



Information and Communication Technologies

# **EPIWORK**

## **Developing the Framework for an Epidemic Forecast Infrastructure**

<http://www.epiwork.eu>

Project no. 231807

---

### **FFCUL Progress Report on WP3**

---

Period covered: 2009.02.01 to 2009.07.31

Start date of project: February 1<sup>st</sup>, 2009

Due date of deliverable:

Distribution: internal

Date of preparation: 2009.09.15

Duration: 36 months

Actual submission date:

2009.09.15

Status:

Project Coordinator: Alessandro Vespignani

Project Coordinator Organisation Name: ISI Foundation

Lead contractor for this deliverable: FFCUL

## Work package participants

The following partners have taken active part in the work leading to the elaboration of this document, even if they might not have directly contributed writing parts of this document:

- Mário J. Silva
- Livia Moreira
- Pedro Gonçalves
- Fabrício Silva
- Francisco Couto
- Luís Lopes
- Nico Stollenwerk

## Change log

Version	Date	Amended by	Changes
1	2009.09.15	mjs	

## Executive Summary

The report includes a summary of the work carried out by FFCUL in the first semester of the project.



---

# FFCUL Progress Report 2009.02.01 to 2009.07.31

Mário J. Silva, Fabricio Silva, Francisco Couto, Luís Lopes

University of Lisbon, LASIGE, Portugal

15th of September 2009

---

## **Abstract**

The report includes a summary of the work carried out by the LASIGE group of FFCUL in the reporting period, the first semester of the project life. The work by the CMAF group of FFCUL in WP1 is reported in a separate document.

**Keyword List:** progress-report, first-semester



## **Contents**

1	Overview .....	4
2	Work in WP1 — Population Models and Contact Networks.....	5
3	Work in WP3 — Information platform.....	6
3.1	Background Information on WP3 .....	6
3.2	Progress in the Reporting Period.....	9
4	Work in WP4 — Epidemic Modelling Platform.....	11
5	Work in WP7 — Management.....	12

# 1 Overview

The Epiwork project started in February 2009. This report summarises the progress done in the first semester of the project activity by the LASIGE Group of FFCUL.

According to the work plan FFCUL is involved in the following work packages:

WP 1	Population Models and Contact Networks
WP 3	Information platform
WP 4	Epidemic Modelling Platform
WP 7	Management

The FFCUL participation in Epiwork involves two groups:

- CMAF Group
- LASIGE Group

The LASIGE Team working on WP3 and W4 in this period includes:

- Mário J. Silva (FCUL Faculty, worked in the reporting period in WP3, WP4 and WP7)
- Fabrício Silva (FCUL Faculty, worked in the reporting period in WP3 and WP4)
- Francisco Couto (FCUL Faculty, worked in the reporting period in WP3)
- Luís Lopes (Post-doc researcher, worked during the reporting period part-time - 50% - while completing coursework on the Masters in Biomedical Informatics at FCUL on various tasks in WP3)
- Hugo Ferreira (Graduate student, hired in April for 3 months with a part-time scholarship, to help in setting up the hardware infrastructure that will support the information platform of WP3)

- Carla Patrícia Sousa (Undergraduate student, hired in April with a scholarship, to help in setting up the hardware infrastructure that will support the information platform and give technical support to the deployed information platform of WP3).
- Graduate student João Zamite worked informally (effort not accounted) with our group in the development of prototypes for epidemic data collection from internet data sources (WP3)

There is a discrepancy in the profiles of the people hired to work on Epiwork at LASIGE and the planned, the reason being that we were unable to fill the software engineer and a post-doc positions as planned, with previous directly related experience and salaries matching our budget. As a result, we have been using Informatics Engineering and Biomedical Informatics students on the infrastructure setup assisted by FCUL faculty and senior technical staff .

LASIGE has hired more people at a reduced cost, which was the contingency measure found to manage the situation. We expect that in the next future they will graduate, acquire the required skills while working in the project and eventually match the envisioned profiles.

## **2 Work in WP1 — Population Models and Contact Networks**

FFCUL Effort in this task: 30 persons.month.

The CMAF group of FFCUL is participating in this task and sending a separate progress report.

### 3 Work in WP3 — Information platform

This task is lead by FFCUL, with a total contribution of 82 persons.month (60 hired technicians + (22) academics).

The effort dedicated to the project in the period was 15 persons month, 13 pm from technicians, and 2pm from permanent staff. This is well above planned, reflecting the decision of hiring more (and less skilled) staff for the LASIGE team of Epiwork.

#### 3.1 Background Information on WP3

Work package number	3	Start date or starting event:				Month 1		
Work package title	Information platform							
Activity type	RTD							
Participant number	12	1	2	3	4	5	9	10
Participant short name	FFCUL	ISI	FGC-IGC	TAU	MPI-DS	AIBV	BIU	FBK-IRST
Person-months per participant	82	60	4	8	42	2	11	6

The whole WP3 activity is structured into four tasks:

#### Task 3.1 – Data Collection.

**Participants:** FFCUL, ISI, FBK-IRST, BIU, MPI-DS, FGC-IGC, AIBV.

**Description:** Realistic simulations of epidemic processes crucially depend on the availability of datasets describing human behaviour and pathogen-host interactions. Datasets include population movement data, social and behavioural



data, health related data, geographic data, detailed geo-temporal epidemic incidence and immunization data, pathogen evolution and multi-strains circulation data. Data can come from a variety of different sources, including hospital records, country statistics, Web content, and others. It can range from a global scale, such as the worldwide air transportation infrastructure, down to the detailed description of individual activities at a minute-by-minute scale. This task will create a catalogue of databases of epidemiological data across Europe, with extensive meta-data describing the main characteristics of the available information sources. This catalogue will be integrated with a collaborative platform that will be setup for online discussion and exchange of meta-data among the participants.

### **Task 3.2 – Meta-Model Design.**

**Participants:** FFCUL, IGC, ISI.

**Description:** While some of the previously mentioned datasets are freely available on the Web (e.g. WHO Global Health Atlas, Eurostat), they are often scattered in different repositories, cover partial regions of the world and come in different formats, according to different standards and classifications. The project envisions a unified and integrated approach for the management of these resources, with the design and implementation of an Epidemic Marketplace Platform, publicly available on the web. The platform supports the sharing and management of epidemic datasets and resources as well as their rating, annotation, and selection. It is an on-line social networking site that will serve researchers, practitioners, and educators all over the world to foster a virtual community for epidemic research. It will support the exchange of resources as well as user interactions. Based on a Web2.0 approach, users will become active participants, sharing information and data, and collaborating online, rather than being satisfied with a passive information consumer/viewer role. We envision proposing a simple reference format, which will facilitate the navigation and use of the datasets. Each dataset will come with a metadata file, signalling the date of submission, the last update, the source of the dataset, a basic profile (e.g., transportation network – Origin-Destination matrix), and a more thorough

description of the dataset and the classification used. The Marketplace will support flexible and intuitive tools for navigation and selection of resources. Standard classifications as well as tagging systems proposed by users will be supported.

### **Task 3.3 – Epidemic Marketplace Platform.**

**Participants:** FFCUL, ISI.

**Description:** This task will implement a platform based on the integration of grid technology and publicly available services and software on the web to support the sharing and management of epidemic datasets and resources as well as their rating, annotation, and selection. The Epidemic Marketplace Platform will be an on-line social networking site that will serve researchers, practitioners, and educators all over the world to foster a virtual community for epidemic research. It will support the exchange of resources as well as user interactions. Based on some of the Web2.0 characteristics, users will become active participants, generating information and providing data for sharing, and collaborating online, rather than being satisfied with a passive information consumer/viewer role. More specifically, researchers can use and contribute to the Marketplace in several different ways. They can: (1) use it as a catalogue of data sources containing the metadata describing existing databases; (2) view, download, tag, and comment on the available resources; (3) provide compliant datasets and relevant information; (4) use it as a forum where to publish information about their own data, seek modellers to collaborate with, share and distribute their new findings.

### **Task 3.4 – Evaluation and monitoring of the use of the catalogue and collaboration services.**

**Participant:** FFCUL.

**Description:** This task involves the monitoring of epidemiological data exchanges performed through the mediating services platform. The evaluation will assess not only the coverage of the catalogued resources, but the users' satisfaction with the user interface and integrated collaborative tools made

available through the epidemiological marketplace platform. More importantly, the analysis of the collected datasets and their annotations and usage will provide a rich environment for deriving an epidemiology ontology, which will help further on the integration and communication among the community of epidemiologists.

### **3.2 Progress in the Reporting Period**

In the first semester the work done by the LASIGE Team was related to Task 3.1 Task 3.2 and Task 3.3. Evaluation work in Task 3.4 will start once the information platform is deployed.

#### **Activities at FFCUL in the first semester of the project in this work package:**

1. Mário Silva and Fabrício Silva attended Epiwork Kick-off Meeting in Torino in February – presentation by Fabricio Silva; discussion with ISI on the joint work on WP3/WP4.
2. Videoconference on integration WP3/WP4
3. Luis Lopes and Fabrício Silva attended WP5 Meeting in Amsterdam in May; presentation by Fabricio Silva and discussions on the Integration of WP3/WP4/WP5
4. Work on the production of Deliverable 3.1
5. Hardware Infrastructure setup
6. Initial design of the SW architecture of the Epidemic Marketplace
7. Development of the first prototype of a data collector

#### **Publications and Presentations:**

1. Submitted paper to Inforum 2009 (<http://inforum.org.pt/INForum2009>), which was accepted for presentation in September at the conference: *Automated Social Network Epidemic Data Collector*. Luis F. Lopes, João M.

Zamite, Bruno C. Tavares, Francisco M. Couto, Fabrício Silva and Mário J. Silva.

2. Eurosurveillance (<http://www.eurosurveillance.org>) submission: *Epidemic Marketplace: an e-Science Platform for Epidemic Modelling and Analysis*. Fabrício A. B. da Silva, Luis Filipe Lopes, Francisco M. Couto and Mário J. Silva. Current Status: under revision after a major review.
3. Presentation in Torino, kickoff meeting of the Epiwork project, February 2nd and 3<sup>rd</sup>, 2009. (<http://www.epiwork.eu/2009/02/03/kickoff-meeting-of-the-epiwork-project/>)
4. Presentation in Amsterdam, WP5 first meeting, 25-26th of May, 2009. (<http://www.epiwork.eu/2009/06/05/first-epiwork-wp5-meeting-in-amsterdam-25-26th-of-may-2009/>)

#### **Activities at FFCUL in the first semester of the project in Task 3.1:**

The data collection activity by the consortium will start once the first functional prototype is deployed and released to the consortium (at the end of the first year). In the first semester, we started with some initial experiments, involving:

- Initial catalogue design
- Design and implementation of a data collection prototype (flu-related tweets)

#### **Activities at FFCUL in the first semester of the project in Task 3.2:**

Work in this task included:

- A review of meta-modelling techniques and existing standards.
- Characterisation of the data sources most commonly used in epidemiological studies.
- Initial design of the epidemic meta-data catalogue

#### **Activities at FFCUL in the first semester of the project in Task 3.3:**

- Definition of the general architecture of the Epidemic Marketplace
- Infrastructure design and identification of equipment to be acquired

- Installation of the hardware and base software (OS)
- Design and implementation of fault tolerance support for the epidemic marketplace: backup and data replication policies
- Services installation, including Epidemic Marketplace's Repository main components: Fedora Commons ([www.fedora-commons.org](http://www.fedora-commons.org)) and Muradora (<http://www.muradora.org/muradora>)
- Initial deployment of a first prototype
- Functional, stress and security testing of the first prototype

#### **Activities at FFCUL in the first semester of the project in Task 3.4:**

- Planning of the monitoring tasks. Actual collection of usage data will start once the initial system is fully deployed.

## **4 Work in WP4 — Epidemic Modelling Platform**

This task is lead by ISI, with a total contribution of 19 persons.month (12 hired + (7) academics).

FFCUL Effort in this task: 19 persons.month.

The effort dedicated to the project in the period was 0.3 persons month, contributed by permanent staff. This is as planned, reflecting the fact that this task is led by ISI and our contribution will intensify later.

#### **Activities at FFCUL in the first semester of the project in this work package:**

- Meeting in Torino, February 2009
- Videoconference in May with ISI, discussions of service-oriented architecture to be deployed and how the two computational platforms will work together and provide services to the consortium and the community.
- Meeting in Amsterdam, May 2009

## **5 Work in WP7 — Management**

This task is lead by ISI.

FFCUL Effort in this task: 4 persons.month.

The effort dedicated to the project in the period was 0.5 persons month, contributed by permanent staff, as planned.

### **Activities at FFCUL in the first semester of the project in this work package:**

1. Attended Epiwork quick-off meeting in Torino, February 2009.
2. Data collection activities for preparation of this report.

# EPIWORK, Report September 2009:

## **CMAF group**

(responsible Nico Stollenwerk)

Universidade de Lisboa, Faculdade de Ciências  
Centro de Matemática e Aplicações Fundamentais,  
Av. Prof. Gama Pinto 2, 1649-003 Lisboa, Portugal

e-mail: nico@ptmat.fc.ul.pt

September 15, 2009

1. Scientific background and activities: Main tasks in Workpackage 1 are modelling and parameter estimation in influenza, seasonal and pandemic, and investigation of network models for the spread of transmittable diseases like influenza and others, especially in the context of spatially restricted networks.

Predictability of outbreaks is in this context of major importance, as it can be quantified by system theories like deterministic chaos and criticality, i.e. prediction horizons given by Lyapunov exponents (especially in simple epidemic already showing large parameter regions of deterministic chaos) and large scale fluctuations of system size as observed near critical thresholds (as they become more and more relevant in evolutionary biological pathogen systems).

These basic notions are vital for the data gathering and analysis in the other work packages of the EPIWORK project, as well as the feedback from the more applied work packages are vital for the modelling and parameter estimation part in workpackage 1.

In accordance with these premisses we from the CMAF team performed and are currently performing the following activities:

We organized one conference special session at the international conference CMMSE in Gijon, Spain, in July 2009, focussing in our presentations and those of other invited participants on influenza modelling and parameter estimation, spatially restricted networks with superdiffusion and predictability in basic epidemiological multi-strain models, as typical for among others influenza and dengue. Published references see below. Based on this activity we are currently invited by one of the editors of Journal of Comp. and Applied Maths. for a special article together with Lewi Stone, leader of Workpackage 1 and Sander van Noort, one of the main scientific initiators of Influenza Net.

We are since several months organizing another special session at an international conference ICNAAM 2009, which will be held in September 2009 in Rethymno, Greece, in collaboration with University Torino, and will include 14 talks on topics similar to the ones mentioned above. Conference contributions are accepted for the proceedings, and will be eligible to publication in international journals. References will be given below.

Other activities performed during the first half year of the project EPIWORK are:

Hiring a post-doctorate scientist from CNRS in Paris, Sebastien Ballesteros, for 2 years (contract signed), who already is expert on modelling influenza up to deterministically chaotic dynamics in wide parameter regions visible via seasonality or multi-strain aspects in SIR-type models and also experienced in parameter estimation in such system, with very detailed data sets available from France.

Sebastien has participated in the special session at CMMSE 2009 in July with a detailed investigation on various models currently applied to influenza, among which is the reinfection model which Gabriela Gomes et al. and Stollenwerk et al. have investigated in the past.

Informal talks have been held with Forschungszentrum Juelich, Germany, and CNRS in Paris, France, each on institute's leaders level, on how to obtain good influenza data, how to build up internet surveillance systems in the respective countries in central Europe, and on scientific and computational aspects involved in WP 1 and EPIWORK as a whole. This has been done in close contact with initiators of Influenza Net in the Netherlands. These contacts have been intensified over the summer.

Networks with spatial restrictions have been intensively investigated by several members of CMAF, inside and outside the Mathematical Biology group, visible through the seminar series at CMAF over the last half year. Ecological aspects of vector borne diseases and evolutionary aspects of influenza like illnesses have been investigated by Frank Hilker and Philip Gerrish, and presented internationally. Frank Hilker is working on "Demographic and ecological interactions of host populations". This task considers mathematical models to study the ecology of infectious diseases, where host demographics are non-trivial (density-dependent) and host populations interact. The aim is to identify mechanisms generating disease emergence, outbreaks, multistability and oscillations. He started work on backward bifurcations in vector-borne disease models, their generality and their consequences in non-autonomous systems (during a visit at University of Bordeaux 2, 15.-26.6.2009) and is reviewing the literature on models of infectious diseases in both prey and predator populations. Philip Gerrish works on "evolution in influenza, shift versus drift", where he interacts closely with our post-doctorate candidate Sebastien Ballesteros.

Predictability in multi-strain epidemiological models and under seasonality is currently investigated by Nico Stollenwerk in collaboration with Maira Aguiar, both CMAF, and Bob Kooi, University of Amsterdam. Progress has been made especially on fast calculations on prediction horizons, results presented in CMAF, at CMMSE in Gijon, Spain, in Belo Horizonte, Brasil. Basic reinfection models necessary to understand spreading of influenza like illnesses have been investigated, publications in international journals are just accepted, further under submission. A book on evolutionary aspects of multi-strain epidemiology has been completed and is currently in production. It will lead to intensified research activities on evolution of influenza viruses and its implications to modelling and data analysis among the students in CMAF and collaborators outside, especially the ones from work package 1 in EPIWORK.



## 2. Scientific dissemination and management:

### 2.1. Talks given to international audience (conferences):

- 4.-8.5.2009      Invited participation of Frank Hilker  
at the American Institute of Mathematics (AIM) workshop  
on "Stochastic and deterministic spatial modeling in population dynamics"  
in Palo Alto CA, USA; presentation on  
"Allee effect and disease transmission".
- 7.5.2009          Invited talk by Philip Gerrish at  
"Comemorao do Bicentenrio de Darwin" on "Tricking Darwin".
- 30.6.-3.7.2009    Talk by Nico Stollenwerk "Analytic likelihood function for data analysis in  
the starting phase of an influenza outbreak"  
at the 'International Conference on Computational  
and Mathematical Methods in Science and Engineering,  
CMMSE 2009' in Gijon, Spain.
- 30.6.-3.7.2009    Talk by Nico Stollenwerk "Fractional calculus and Levy flights:  
modelling spatial epidemic spreading"  
at the 'International Conference on Computational  
and Mathematical Methods in Science and Engineering,  
CMMSE 2009' in Gijon, Spain.
- 30.6.-3.7.2009    Talk by Sebastien Ballesteros (successfully hired on EPIWORK position)  
"Introducing gradual antigenic drift in co-circulating  
cross reactive antigenic cluster models"  
at the 'International Conference on Computational  
and Mathematical Methods in Science and Engineering,  
CMMSE 2009' in Gijon, Spain.
- 30.6.-3.7.2009    Talk by Maíra Aguiar (co-authors N. Stollenwerk, B. Kooi) "Computational aspects  
in the investigation of multi-strain dengue models"  
at the 'International Conference on Computational  
and Mathematical Methods in Science and Engineering,  
CMMSE 2009' in Gijon, Spain.
- 27.-30.7.2009    Contributed talk by Frank Hilker on "Complex wildlife disease  
transmission dynamics in populations with demographic Allee effect"  
at the International Conference on Mathematical Biology  
and Annual Meeting of The Society for Mathematical Biology,  
University of British Columbia, Vancouver, Canada.
- 18.-22.9.2009    Talks at the '7th International Conference of Numerical  
Analysis and Applied Mathematics, ICNAAM 2009'  
in Rethymno, Greece, by Phillip Gerrish, Nico Stollenwerk and Maíra Aguiar.
- 2630.9.2009      Talk by Philip Gerrish at "Understanding the emergence  
of infectious disease" in Roscoff, France, on  
"The promise of recombination inhibitors".

## 2.2. Invited talks given to national and international audience (institutes) and visits:

- |                 |   |
|-----------------|---|
| 3.-4.2.2009     | Talk by Nico Stollenwerk on "Mathematical modeling and data analysis in epidemiology and population biology" at the kick-off meeting for the EU project EPIWORK at ISI, Torino, Italy. Participation in this meeting by Frank Hilker and Philip Gerrish             |
| 10.2.2009       | Talk by Nico Stollenwerk "From simple spatially extended epidemic models towards realistic spreading of diseases" at CMAF, Universidade de Lisboa, Portugal.  |
| 9.3.2009        | Coordination meeting with the FCG-IGC partners at CMAF: CMAF contributes to the following: (i) "Demography and density thresholds": the disease reproduction potential ('reverse' density thresholds); (ii) models with predation as transmission pathway.          |
| 28.4.2009       | Talk by Sebastien Ballesteros "Disentangling non-linear dynamics and punctuated immune escape in complex recurrent pattern of human influenza A" at CMAF, Universidade de Lisboa, Portugal.   |
| 19.5.2009       | Talk by Nico Stollenwerk "Epidemiology of Dengue Fever: A Model with Temporary Cross-Immunity and Possible Secondary Infection Shows Bifurcations and Chaotic Behaviour in Wide Parameter Regions" at Universidade Federal de Minas Gerais, Belo Horizonte, Brasil. |
| 2630.9.2009     | Talk by Philip Gerrish at Roscoff, France, on "The promise of recombination inhibitors"   |
| Feb./March 2008 | visits by Nico Stollenwerk to FZJ Jülich, Germany, and CNRS Paris, France, for the EU project EPIWORK.  |
| June 2009       | invited talk and extended visit by Philip Gerrish to the Instituto de Ecologia, Xalapa, Mexico, talk on "Genetic linkage and mutation rate instability"   |

## 2.3 Poster presentations at international conferences:

- |               |   |
|---------------|---|
| 18.-22.9.2009 | Poster "New chaotic attractor in dengue: Positive Lyapunov exponent in multi-strain model with temporary cross-immunity" during the '7th International Conference of Numerical Analysis and Applied Mathematics, ICNAAM 2009' at Rethymno, Crete, Greece. |
|---------------|---|

## References

Publications in refereed international journals:

- [1] Martins, J., Pinto, A., & Stollenwerk, N. (2009) A scaling analysis in the SIRS epidemiological model, *Journal of Biological Dynamics* **3**, 479–496.
- [2] Aguiar, M., Stollenwerk, N., & Kooi, B. (2009) Torus bifurcations, isolas and chaotic attractors in a simple dengue fever model with ADE and temporary cross immunity, *accepted for publication in Intern. Journal of Computer Mathematics*.
- [3] Martins, J., Aguiar, M., Pinto, A., & Stollenwerk, N. (2009) On the series expansion of the spatial SIS evolution operator, *accepted for publication in Journal of Difference Equations and Applications*.

Books:

- [4] Stollenwerk, N. & Jansen, V.A.A. (2009) **Population Biology and Criticality**, *From critical birth-death processes to self-organized criticality in mutation pathogen systems: The mathematics of critical phenomena in application to medicine and biology*, (book in production by Imperial College Press, London).

Refereed conference contributions in scientific books:

- [5] S. van Noort, N. Stollenwerk and L. Stone, “Analytic likelihood function for data analysis in the starting phase of an influenza outbreak”, *Proceedings of 9th Conference on Computational and Mathematical Methods in Science and Engineering, CMMSE 2009*, ISBN 978-84-612-9727-6, edited by Jesus Vigo Aguiar *et al.*, Salamanca, 2009, pp. 1072–1080.
- [6] N. Stollenwerk, M. Aguiar and B. W. Kooi “Computational aspects in the investigation of chaotic multi-strain dengue models” *Proceedings of 9th Conference on Computational and Mathematical Methods in Science and Engineering, CMMSE 2009*, ISBN 978-84-612-9727-6, edited by Jesus Vigo Aguiar *et al.*, Salamanca, 2009, pp. 995–1002.
- [7] J.P. Boto and N. Stollenwerk, “Fractional calculus and Levy flights: modelling spatial epidemic spreading”, *Proceedings of 9th Conference on Computational and Mathematical Methods in Science and Engineering, CMMSE 2009*, ISBN 978-84-612-9727-6, edited by Jesus Vigo Aguiar *et al.*, Salamanca, 2009, pp. 177–188.
- [8] S. Ballesteros, A. Camacho and B. Cazelles, “Introducing gradual antigenic drift in co-circulating cross reactive antigenic cluster models”, *Proceedings of 9th Conference on Computational and Mathematical Methods in Science and Engineering, CMMSE 2009*, ISBN 978-84-612-9727-6, edited by Jesus Vigo Aguiar *et al.*, Salamanca, 2009, pp. 1471–1482.
- [9] Nico Stollenwerk (2009) From dynamical processes to likelihood functions, an application to internet surveillance data for influenza like illnesses (accepted contribution to ICNAAM 2009, Sept.)
- [10] Maíra Aguiar, Bob W. Kooi, Nico Stollenwerk (2009) Multi-strain deterministic chaos in dengue epidemiology, a challenge for computational mathematics (accepted contribution to ICNAAM 2009, Sept.)
- [11] Nico Stollenwerk, João Pedro Boto (2009) Reaction-superdiffusion systems in epidemiology, an application of fractional calculus (accepted contribution to ICNAAM 2009, Sept.)

Posters, preprints or in preparation:

- [12] Aguiar, M., & Stollenwerk, N. (2009) New chaotic attractor in dengue: Positive Lyapunov exponent in multi-strain model with temporary cross-immunity (*poster to be presented at ICNAAM 2009, 18-22 September 2009, Rethymno, Crete, Greece*).
- [13] N. Stollenwerk, S. van Noort, J. Martins, M. Aguiar, F. Hilker, A. Pinto, & G. Gomes (2009) A spatially stochastic epidemic model with partial immunization shows in mean field approximation the reinfection threshold, *submitted*.
- [14] N. Stollenwerk, S.-Ch. Park, M. Aguiar, J. Martins, G. Gomes and A. Pinto (2009) Exact phase transition lines of spatially stochastic SIRS epidemics, *in preparation*.